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HOST RANGE AND HOST PREFERENCES OF *DENDROPHTHOE FALCATA* AND *SCURRULA PULVERULENTA* (LORANTHACEAE) IN THE FORESTS OF POTOHAR AND ADJACENT REGIONS

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Abstract

Host range and host preferences of *Dendrophthoe falcata* and *Scurrula pulverulenta* were studied in the Himalayan foothills region of Potohar plateau, Pakistan. *Dendrophthoe falcata* and *S. pulverulenta* were recorded in different areas of Rawalpindi-Islamabad districts and at each site in these areas host range of both the mistletoes were recorded. Both mistletoes parasitise a variety of dicotyledonous trees. Although both mistletoes are generalist species, with *S. pulverulenta* recorded on 37 different hosts and33 hosts recorded for *D. falcata, they are most often found on a subset of these.* Based on frequency of occurrence, *Senegalia modesta* is the primary host for *D. falcata*, *Bombax ceiba* is the secondary host and *Flacourtia indica* is the tertiary host, while *Olea ferruginea* is the primary host for *S. pulverulenta*, *Punica granatum* is secondary host and *Senegalia modesta*, *Ficus palmata* and *Pyrus pashia* are tertiary hosts.

Key words: *Dendrophthoe falcata, Scurrula pulverulenta,* Host range, Host preferences, Potohar, Mistletoes.

Introduction

Parasitic organisms are partly or entirely dependent upon their host for completion of their life cycle. Parasitic organisms can be generalists, parasitising a wide range of unrelated hosts, or specialists, sometimes utilising a single host species (Norton & Carpenter, 1998). Even in generalist species, sometimes only a component of the available range of host species is preferentially utilised in a particular geographic region (Sultan *et al*., 2018). The distribution of parasitic plants is governed by the availability and distribution of suitable host species (Sultan *et al*., 2018). Stem parasites may vary from generalist to specialist, even among closely related species (Heide-Jorgensen, 2008).

Angiosperms that morphologically and physiologically attach to other flowering plants by means of a haustorium have evolved 12 times independently resulting in 292 genera and ca. 4750 species from 31 families (Nickrent, 2020; 2021). They can either be hemiparasitic, capable of photosynthesis, or holoparasitic, entirely reliant upon the host for nutrients (Heide-Jorgensen, 2008). Mistletoes are obligate parasites in the sense that they cannot complete their life cycle in the absence of their host, however they are capable of photosynthesis and rely to some extent on their host for photosynthates and for water and minerals. The mistletoe habit (aerial parasitism) has evolved five times independently in Santalales (Nickrent *et al*., 2010 Watson, 2001), and two of these events (Loranthaceae and Viscaceae) are the most speciose families in the order (Nickrent *et al*., 2019). Loranthaceae comprises 73 genera which are mostly aerial hemiparasites, however three monotypic genera are mainly root parasitic. The family is distributed mainly in tropical areas globally and also found in Australia, South America, Europe, New Zealand and Asia (Vidal- Russell & Nickrent, 2007).

Mistletoes are sometimes damaging pathogens of fruit trees and timber yielding trees (Knutson, 1983, Thriveni *et al*., 2010). Dwarf mistletoes (*Arceuthobium* spp.) which parasitise conifers in the families Pinaceae and Cupressaceae (Hawksworth & Wiens, 1996), for example, cause annual wood loss up to 500 million cubic feet in North America (Shea & Howard, 1969) and up to 150 million cubic feet in British Columbia (Baranyay & Smith, 1972). Mistletoes damage growth, reduce wood quality and quantity, lower host vigour, and reduce fruiting and predispose trees to insects attack, disease and fungi (Hawksworth, 1980). Thus, the mistletoes are true threats to silviculture and horticultural crops (Thriveni *et al*., 2010)).

According to the Flora of Pakistan (Abdulla, 1973) mistletoes are represented by nine species in Pakistan - *Viscum album* L., *V. cruciatum* Sieber ex Spreng., *Korthalsella opuntia* (synonym of *K. japonica* (Thunb.) Engl.), *Loranthus cordifolius* (syn. of *Scurrula cordifolia* (Wall.) G. Don), *L. vestitus* (syn. of *Taxillus vestitus* (Wall.) Danser), *L. longiflorus* (syn. of *Dendrophthoe falcata* (L. f.) Ettingsh.), *L. pulverulentus* (synonym of *Scurrula pulverulenta* (Wall.) G. Don), *Arceuthobium oxycedri* M. Bieb. and *A. minutissimum* Hook. f. While *Viscum dryophilum* Rech. f. (parasitic on *Quercus baloot*) was later described from South Waziristan (Kaniguram) and eastern Afghanistan by Rechinger (1976). The following common host-mistletoe combinations have been recorded. *Korthalsella japonica* predominantly occurs on *Quercus* spp., which are a valuable source of fodder during winter months (Khan, 1980; Zakaullah,

1988). *Viscum album* is parasitic on horse-chestnut, willow, apricot, poplar and walnut while *Viscum cruciatum* is mostly parasitic on olive trees (Abdulla, 1973). *Arceuthobium minutissimum* causes great damage to *Pinus wallichiana* Jackson especially in the Upper Swat region and near Astore while *Arceuthobium oxycedri* is parasitic on *Juniperus polycarpos* C. Koch in Balochistan (Abdulla, 1973). *Loranthus cordifolius* is parasitic on *Quercus dilatata* Lindl., *Phyllanthus emblica* Linn. and species of *Platanus* Linn. (Abdulla, 1973).

Host range of *Dendrophthoe falcata*: *Dendrophthoe falcata* has a very broad host range - the second largest amongst the phanerogamic parasites (Ray & Dasgupta, 2011), following *Viscum album* which has a host range of 452 taxa (Barney *et al*., 1998). Hawsworth *et al*., (1993) enumerated 401 host species from 227 genera in 77 families for *D. falcata*. Johri & Bhatnagar (1972) recorded 311 species from 177 genera in 57 families for *Dendrophthoe falcata*, their host list updated Singh (1962). There have been numerous regional studies on the host range of *Dendrophthoe falcata* in the subcontinent. Baloch & Mohyuddin (1969) recorded 10 host species from nine genera in seven families from Rawalpindi district. Zakaullah *et al*., (1984) investigated the occurrence of *Dendrophthoe falcata* in the east region of Rawalpindi district and recorded 23 species from 22 genera in 16 families. Hasan & Samad (2019) recorded *D. falcata* on 50 species from 39 genera in 21 families in Rajshahi city and vicinities in Bangladesh. In a contribution to host range of *D. falcata* Rao & Ravindranath (1964) recorded 13 new hosts from 13 genera in 13 families for *Dendrophthoe falcata* from Hyderabad-Secunderabad area of India. Gosh *et al*., (1984) recorded *Dendrophthoe falcata* on *Anacardium occidentale, Mangifera indica and Schleichra oleosa* in Kerala, India, while *D. falcata* var. *pubescens* was recorded on 11 hosts from 11 genera in 8 families. Thriveni *et al*., (2010) recorded mistletoe hosts in Karnataka, India. They recorded 98 hosts in 70 genera from 30 families. Joshi & Soni (2013) studied the host range of *Dendrophthoe falcata* in Gujarat State Fertilizer Company Township, Vadodara in Gujarat state of India. They recorded 28 species from 26 genera in 18 families. Singh & Gupta (2013) studied the host range of *Dendrophthoe falcata* in district Champaran in North Bihar, India. They recorded 10 species from nine genera in five families. Rothe & Maheshwari (2017) recorded five new hosts in five genera from five families for *Dendrophthoe falcata* from Melghat in Amravati district of Maharashtra state of India.

Host range of *Scurrula pulverulenta*: *Scurrula pulverulenta* was recorded on seven hosts in seven genera from six families in Khimti forest in Nepal (Devkota, 1977). Zakaullah *et al*., (1984) investigated the occurrence of *Scurrula pulverulenta* in the east region of Rawalpindi district and recorded nine species from nine genera in five families. Pundir (1995) recorded 81 host species from 58 genera in 34 families for India. Joshi & Devkota (2010) recorded 14 species from 10 genera in nine families for *Scurrula pulverulenta* from Nepal.

Economic importance: Knutson (1983) reported the occurrence of *Dendrophthoe* on *Citrus*, fig, guava and mulberry in India and of *Scurrula pulverulenta* on *Citrus* in Philippines and Indonesia. *Dendrophthoe falcata* and *Scurrula pulverulenta* produced extreme growth, top dying, thin foliage and abnormal swellings in the host (Zakaullah *et al*., 1984). According to Huaxing & Gilbert (2003), *S. pulverulenta* has been recorded as forming dense, damaging infestations of *Citrus* orchards in India and Nepal. *Dendrophthoe falcata* is the most destructive parasite of teak in plantations (Gosh *et al*., 1984). Poor growth and high mortality rate was associated with heavy mistletoe infestation in Nilumbur Forest Division, as a consequence teak plantations were clear felled (Ranganathan, 1982). In Kerala (India), *D. falcata* is again one of the major pests of teak plantations, infesting more than 80% of the trees in some plantations and causing a heavy loss and often led to total failure of plantations in Nilambur when young trees were heavily attacked (Gosh *et al*., 1984). *Dendrophthoe falcata* also attacks horticultural crops like *Artocarpus heterophyllus* Lamk., *Syzygium jambos* (Linn.) Alston and *Psidium guajava* Linn (Gosh *et al*., 1984).

Materials and Methods

Host range and host preferences of *Dendrophthoe falcata* (Figs. 1-6) and *Scurrula pulverulenta* (Figs. 7-14) were recorded in Himalayan foothills of Potohar plateau. Potohar plateau comprises Rawalpindi, Islamabad, Attock, Jehlum and Chakwal districts. Targeted surveys were conducted to record the hosts at different sites (Table 1). The following areas were surveyed and at each site all host-mistletoe combinations were recorded and frequency of each mistletoe on different host species was also recorded.

Table 1. List of study sites.

District	Tehsil	Locality
Rawalpindi	Kotli Sattian	Mohri Saydan
		Mohra Beru
		Salooni
		Lehtrar
		Bandi Jillari
		Dalhorh
		Lehtrar Payen
		Lehtrar-Kahuta Road
		Bagga Morh
		Dhoke Jandala
		Dhoke Kanala Moza Jilla
		Neela Sand
	Kahuta	Panjarh
		Kaltia Baheend
		Panjar-Azad Pattan Road
		Moza Barota Kahuta
		Beor
		Narar
Islamabad	Islamabad	Nurpur
		Kumlarhi
		Shahdara road
		Dhoke Mitha

Fig. 1a. Flowers of *Dendrophthoe falcata*

Fig. 1b. Flowers of *Dendrophthoe falcata*

Fig. 2. Developing fruits of *Dendrophthoe falcata*

Fig. 3. Mature fruits of *Dendrophthoe falcata*

Fig. 4. *Dendrophthoe falcata* on *Senegalia modesta*.

Fig. 5. *Dendrophthoe falcata* on *Bombax ceiba*.

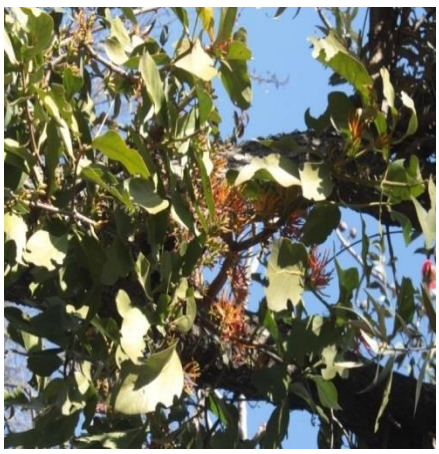

Fig. 6. *Dendrophthoe falcata* on *Olea ferruginea*.

Fig. 7. Flowers of *Scurrula pulverulenta*.

Fig. 8. Fruits of *Scurrula pulverulenta*.

Fig. 9. (Wallnut tree) *Juglans regia* tree heavily infested by *Scurrula pulverulenta*.

Fig. 10. *Scurrula pulverulenta* on *Nerium* oleander.

Fig. 11. *Scurrula pulverulenta* on *Pyrus pashia*.

Fig. 12. *Scurrula pulverulenta* on *Olea ferruginea*.

Fig.13. *Ficus palmata* tree heavily infested by *Scurrula pulverulenta*.

Fig. 14. *Scurrula pulverulenta* on *Morus nigra*.

Table. 2. Locality-wise host use pattern of *Dendrophthoe falcata*.

Locality	Primary host *Senegalia modesta*	Secondary host *Bombax ceiba*	Tertiary host *Flacourtia indica*	Occasional host	Rare host
Morhi Syedan	+	+	+	*Ficus auriculata*	
Mohra Beru	+	+		*Ficus palmata, Flacourtia indica, Morus* sp., *Albizzia lebbek*	
Dalhorh	+			*Albizzia lebbek, Mallotus philippinensis*	*Carissa opaca, Populus nigra*
Kahuta to Lehtrar	+		+		
Dhok Mitha	+				
Bandi Jilari	+	+	+		
Kultia Baheend		+	+		
Neela Sand			+		
Kumlarhi, Rumli			+	*Lamnea coromandelica*	*Pistacia integerrima*
Beor	+	+			*Catunaregam spinosa, Ehretia laevis, Kydia calycina, Grewia elastica, Woodfordia fruticosa*
Mansi Jilla		+			
Nurpur		+			
Rumli	+	+			
Dhoke Jandala				*Ziziphus mauritiana*	
Lehtrar Road				*Melia azedarach*	
Bandi Jillari				*Ficus racemose*	
Lehtarar Paein					*Pyrus pashia*
Moza Barota, Kahuta				*Dalbergia sissoo*	

Host range data were also collated from herbarium collections at National Herbarium of Pakistan (Stewart Collection), National Agricultural Research Centre, Islamabad. A Shannon-Weiner index was used to determine the level of host diversity for each species following Norton & de Lange (1999) who used this index to determine the level of host specificity in Loranthaceous mistletoes of New Zealand, which is determined by the following formula:

$$\text{SW diversity index} = \sum[(pi) \times \ln (pi)]$$

where pi is the proportion of total host records represented by the species i obtained by dividing the number of individuals of species by total number of records.

On the basis of relative host record numbers, the most commonly encountered hosts were declared primary hosts, frequently encountered hosts were designated secondary hosts, the hosts recorded from few locations were considered as tertiary hosts, hosts which are not usually parasitized and only parasitized in location where they co-occur with mistletoe populations were categorized as occasional hosts after Sultan *et al*., (2018). Hosts known from unique or rare co-occurrences were considered as rare hosts. Nearest neighbour sampling and determination of Specialist/ generalist index (G) and resource preference scores (ω) were carried out following Milner *et al*., (2020). Whereby, for each target mistletoe species, ten woody plants close to each of the infected host in each of 25 sample plots were identified to species, going as far as required to get the 10 nearest neighbours. All dominant vegetation types were examined for occurrence of mistletoes. These potential hosts reflect those individuals most likely to receive mistletoe seeds within the sample plot. Nearest neighbours were recorded if they had a diameter at breast height (DBH) > 15 cm, and were considered single individual if multiple trunks were touching at the base. Nearest neighbour data for each woody plant species sampled were split into two variables: number of individuals infected (used resources), and number uninfected (unused resources) for each target mistletoe species (Milner *et al*., 2020).

Results

Senegalia modesta is the primary host for *D. falcata*, *Bombax ceiba* is the secondary host and *Flacourtia indica* is the tertiary host (Table 2, Fig. 15). *Olea ferruginea* is the primary host for *S. pulverulenta, Punica granatum* is secondary host while *Senegalia modesta, Ficus palmata* and *Pyrus pashia* are tertiary hosts (Table 4, Fig. 15).

Both mistletoe species are distributed in Islamabad and Rawalpindi districts only within the Potohar region (Fig. 17).

The hosts recorded for *Dendrophthoe falcata* comprise 33 species from 25 genera in 14 families (Table 3). The primary, secondary and tertiary hosts (Table 2) parasitised by *D. falcata* are all trees and all belong to either the Rosid-I (Fabidae) or Rosid-II (Malvidae) clades of the APG IV classification (Stevens, 2001-onwards).

Table 3. Host list for *Dendrophthoe falcata* (1–record supported by a herbarium specimen showing the host branch with mistletoe or record based on observation during current studies/communication from a reliable source; 2–record on the herbarium sheet without host being collected; 3–literature record).

Host family	Host genus	Host species	Reliability level		
			1	2	3
Anacardiaceae	*Lannea*	*L. coromandelica*	Pers. Obs.		Zakaullah *et al*., (1984), Hawksworth *et al*., (1993)
	Pistacia	*P. chinensis* subsp. *Integerrima*	Pers. Obs.		Zakaullah *et al*., (1984), Hawksworth *et al*., (1993)
Apocynaceae	*Carissa*	*C. spinarum*	Pers. Obs.		Zakaullah *et al*., (1984), Hawksworth *et al*., (1993)
Boraginaceae	*Ehretia*	*E. laevis*	Pers. Obs.		Zakaullah *et al*., (1984), Hawksworth *et al*., (1993)
Euphorbiaceae	*Mallotus*	*M. philippinensis*	Pers. Obs.		Zakaullah *et al*., (1984); Baloch & Mohyuddin (1969), Hawksworth *et al*., (1993)
Fabaceae	*Albizzia*	*A. lebbek*	Pers. Obs.		Zakaullah *et al*., (1984); Baloch & Mohyuddin (1969), Hawksworth *et al*., (1993)
	Dalbergia	*D. sissoo*	Pers. Obs.		Zakaullah *et al*., (1984); Baloch & Mohyuddin (1969), Abdulla, 1973, Hawksworth *et al*., (1993)
	Senegalia	*S. modesta*	Pers. Obs.		Zakaullah *et al*., (1984); Baloch & Mohyuddin (1969), Hawksworth *et al*., (1993)
Lythraceae	*Woodfordia*	*W. fruticose*	Pers. Obs.		Zakaullah *et al*., (1984), Hawksworth *et al*., (1993)
Malvaceae	*Bombax*	*B. ceiba*	Pers. obs.		Zakaullah *et al*., (1984); Baloch & Mohyuddin (1969)
	Grewia	*G. elastica*	Pers. obs.		Hawksworth *et al*., (1993)
		G. optiva			Zakaullah *et al*., (1984)
	Kydia	*K. calycina*	Pers. Obs.		Hawksworth *et al*., (1993)
Meliaceae	*Melia*	*M. azedarach*	Pers. Obs.		Zakaullah *et al*., (1984); Baloch & Mohyuddin (1969), Hawksworth *et al*., (1993)
Moraceae	*Ficus*	*F. racemosa*	Pers. Obs.		Hawksworth *et al*., (1993)
		F. auriculata	Pers. Obs.		Hawksworth *et al*., (1993)
		F. palmata	Pers. Obs.		Zakaullah *et al*., (1984), Hawksworth *et al*., (1993)
		F. religiosa			Baloch & Mohyuddin (1969), Hawksworth *et al*., (1993)
		F. sp.			Baloch & Mohyuddin (1969)
	Morus	*M. alba*			Zakaullah *et al*., (1984), Hawksworth *et al*., (1993)
		M. sp.	Pers. Obs.		Baloch & Mohyuddin (1969)
Oleaceae	*Olea*	*O. ferrugínea*	Pers. Obs.		Baloch & Mohyuddin (1969), Hawksworth *et al*., (1993)
Rhamnaceae	*Ziziphus*	*Z. mauritiana*	Pers. Obs.		Hawksworth *et al*., (1993)
		Z. nummularia			Zakaullah *et al*., (1984), Hawksworth *et al*., (1993)
Rosaceae	*Prunus*	*P. armeniaca*	.		Zakaullah *et al*., (1984), Hawksworth *et al*., (1993)
	Pyrus	*P. pashia*	Pers. Obs.		Hawksworth *et al*., (1993)
Rubiaceae	*Catunaregam*	*C. spinosa*	Pers. Obs.		Hawksworth *et al*., (1993)
	Wendlandia	*W. heynei* (Schult.) Santapau & Merchant (=*W. exserta* (Roxb.) DC.)			Zakaullah *et al*., (1984), Hawksworth *et al*., (1993)
Salicaceae	*Flacourtia*	*F. indica*	Pers. Obs.		Zakaullah *et al*., (1984)
	Populus	*P. nigra*	Pers. Obs.		
	Salix	*S.* x *euramericana*			Zakaullah *et al*., (1984)
		S. acmophylla			Zakaullah *et al*., (1984)
	Xylosma	*X. longifolia*			Zakaullah *et al*., (1984)
14 families	25 genera	33 taxa			
Indigenous	25 genera	33 taxa			

Table. 4. Locality-wise host use pattern of *Scurrula pulverulenta*.

Locality	Primary host *Olea ferruginea*	Secondary host *Punica granatum*	Tertiary host *Senegalia modesta*	Occasional host	Rare host
Panjarh					
Kultia Baheend	+				
Lehtrar Kahuta Road	+	+			
Near Bagga Morh, Lehtrar	+				
Mohra Beru	+	+	+	*Flacourtia indica*, *Pyrus pashia*, *Malus pumila*	*Citrus jambhiri*
Lehtrar	+	+		*Morus* sp., *Ficus palmata*	*Callistemon*, *Lantana camara*
Salooni	+	+			*Juscticia adhatoda*, *Ficus semicordata*
Dhoke Jandala	+	+		*Pyrus pashia*, *Dalbergia sissoo*	*Ficus semicordata*, *B. papyrifera**, *Psidium guajava*, *Vitex negundo*
Forest Rest House, Lehtrar		+	+		*Nerium oleander*, *Duranta erecta*, *Maclura pomifera**
Narar Road near Forest Rest House, Panjar		+		*Ficus benghalensis*	
Narar Road	+	+	+	*Bauhinia variegate*	
Panjar-Azad Pattan Road		+	+	*Dalbergia sissoo*, *Pistacia*, *Mallotus philippinensis*	*C. oppositifolia*
Morhi Syedan					
Lehtrar Payen					*P. integerrima*
Mansi Jhilla					*J. regia*
Bandi Jhaliar					*R. pentapomica*, *Grewia optiva*, *Celtis* sp.
Dhoke Kanala, Moza Jhilla				*S. acmophylla*, *F. auriculata*	*Morus nigra*, *Popolus nigra*, *Prunus armeniaca*
Biyaga Road, Lehtrar	+			*Dalbergia sissoo*	*Carissa spinarum*

The hosts recorded for *Scurrula pulverulenta* comprise 37 species from 31 genera in 18 families (Table 5). The primary, secondary and tertiary hosts (Table 4) parasitised by *S. pulverulenta* are all trees and all belong to Asterid-I, Rosid-II (Malvidae) and Rosid-I (Fabidae) clades of the APG IV classification (Stevens, 2001-onwards). *Scurrula pulverulenta* was recorded on six non-native hosts from six genera in four families - *Lantana camara*, *Duranta erecta* (Verbenaceae), *Callistemon* sp. (Myrtaceae), *Populus nigra* (Salicaceae) and *Maclura pomifera*, *Broussonetia papyrifera* (Moraceae).

Double parasitism was recorded in Mohra Beru, where *D. falcata* and *S. pulverulenata* occur sympatrically and were both found parasitizing individual *Senegalia modesta* hosts (Fabaceae).

Dendrophthoe falcata and *Scurrula pulverulenta* are both generalist species with Shannon-Wiener index values of 2.64 and 2.98, respectively.

Specialist/generalist index (G) and resource preference scores (ω) based on nearest neighbour sampling: Of the 275 trees sampled for nearest neighbours, 47 individuals were infected with *D. falcata*. Sampling identified 40 plant species of which 10 species were hosts for *D. falcata*. This contrasts with *S. pulverulenta* where 119 of 275 individual plants sampled were infected with the mistletoe. These infected individuals were from 20 species out of 45 encountered during sampling. To quantitatively test the specialisation of these mistletoes preference scores (ω) and Specialist/Generalist index (G) were calculated. Based on resource selection ratios—the proportion of hosts to potential hosts (nearest neighbours)—preference scores (ω) were calculated to test if either mistletoe significantly preferred or avoided hosts. Of the ten hosts used by *D. falcata* ω shows that the mistletoe significantly preferred two of its hosts (*Senegalia modesta* and *Flacourtia indica*) and significantly avoided two hosts (*Dalbergia sissoo* and *Olea ferruginea*) (Fig. 16a). However, the results of the significantly avoided hosts must be treated with caution as there were <5 host-mistletoe interactions recorded. The remaining six host species of *D. falcata* were used in proportion to their availability in the environment, with caution in interpretation of results for all species except *Bombax ceiba* (Fig. 2a).

Interestingly none of the 20 host species used by *S. pulverulenta* were identified as significantly preferred hosts (Fig. 16b). The preference scores (ω) suggest all hosts were used in proportion to their availability in the environment, however 11 of these results should be treated with caution (Fig. 16b). Whereas in the current study 275 individual hosts and nearest neighbours were examined for presence or absence of mistletoes, the fact that for both mistletoe species, many of the preference scores for host species are to be treated with caution suggests further sampling in other parts of their distributional range may be required.

The Specialist/Generalist scores (G) for *D. falcata* and *S. pulverulenta* were 0.29 and 0.45 respectively suggesting that within the study area *D. falcata* is more of a specialist parasite compared to *S. pulverulenta*. *Dendrophthoe falcata* appears to have more specialist traits than *S.*

pulverulenta over the study area. The specialist traits that *D. falcata* display are a significant preference for some of its hosts and a smaller Specialist/Generalist index (G) than *S. pulverulenta*. Milner *et al*., (2020) suggested that mistletoes with a G value between 0.2-0.4 are specialist parasites while mistletoes with G value > 0.4 are generalist parasites. Both mistletoes in this study had a larger G value than the highly specialised mistletoe *Amyema lucasii* (G = 0.11; Milner *et al*., 2020).

Discussion

The current study shows that most of the primary and secondary hosts of *Dendrophthoe falcata* and *Scurrula pulverulenta* are common and widespread species in the Potohar plateau, suggesting that mistletoe distributions are not limited by the absence of hosts. For example, *Senegalia modesta* which is primary host for *Dendrophthoe falcata* and *Olea ferruginea* which is a primary host for *Scurrula pulverulenta* species are the most common and dominant species in the scrub forests of Potohar plateau. Likewise, *Bombax ceiba* (secondary host for *Dendrophthoe falcata*), *Punica granatum* (secondary hosts for *Scurrula pulverulenta*), are also common and widespread species in the Himalayan foothill zones. Studying the host range of *Korthalsella* species in New Zealand Sultan *et al*., (2018) also found that primary and secondary hosts of *Korthalsella* species were common and widespread species. Fabaceae accounted for highest number of records for *D. falcata* (69 hosts) in Hawksworth *et al*., (1993). *Acacia* (Mimosaceae) and *Ficus* (Moraceae) both had 16 host species. The other frequently infected genera were *Citrus* (Rutaceae), *Syzygium* (Myrtaceae) and *Terminalia* with 8 host species. It is interesting to note that although *Cassia fistula* was recorded as a host for *D. falcata* in Hawksworth *et al*., (1993), despite being common in the study area it has not been seen to host *D. falcata*. Likewise, there are some gymnosperm records for *D. falcata* viz., on *Araucaria cookii* in West Bengal (Ray and Dasgupta, 2011), *Juniperus communis* (Padate, 1980), *Pinus excelsa* (Pundir, 1990), *Pinus kesiya* (Shaw, 1993), *Pinus longifolia* (Troup, 1921), *Pinus roxbhurghii* (Bakshi, 1976) and *Taxodium distichum* (Hawksworth *et al*, 1993) and for *S. pulverulenta* on an introduced gymnosperm – *Taxodium mucronatum* in India (Pundir, 1997) and on exotic gymnosperm *Metasequoia glyptostroboides* in Nepal (Devkota and Kunwar, 2005) but no gymnosperms are utilized as hosts by the two mistletoes in the Potohar plateau, although *Pinus roxburghii* is quite common in the study area.

It is interesting to note that although mistletoe hosts are common throughout the Potohar plateau, mistletoes are distributed only at relatively higher altitudes in Rawalpindi-Islamabad districts. No mistletoes were found in Attock, Chakwal, Jehlum districts.

Both species have minimal host overlap at primary and secondary level, which demonstrates taxonomic resource partitioning and is advantageous in terms of minimizing competition for available host trees in the area. Studying the host range, host specificity, regional host preferences and genetic variability of *Korthalsella* Tiegh. (Viscaceae) mistletoes in New Zealand Sultan *et al* (2018) also found that despite some host overlap, the three *Korthalsella* species found in New Zealand amply demonstrate taxonomic host partitioning in terms of utilisation of the available flora, since *K. clavata* and *K. lindsayi* share hosts only at the tertiary level and beyond, and *K. salicornioides* only occasionally uses the main hosts of the other two species. Thus virtually eliminating interspecific competition among the mistletoe species.

Six exotic hosts were recorded for *S. pulverulenta* (Table 4) while no exotic host was recorded for *D. falcata*. The occurrence of *S. pulverulenta* on fruit trees (*Psidium guajava, Malus pumila, Prunus armeniaca, Punica granatum, Morus* sp., *Morus alba, Citrus jambhiri, Juglans regia, Ziziphus mauritiana, Ficus palmata*) and of *D. falcata* on *Morus* sp., *Ficus palmata, Prunus armeniaca, Ziziphus nummularia* and *Ziziphus mauritiana* means that these mistletoes may potentially pose problems for fruit culture in these areas. Likewise, the occurrence of both mistletoes on *Dalbergia sissoo* is also a threat to this economically important tree, utilized as a source of valuable timber.

Host–mistletoe combinations are dynamic and expansion in the host range may also occur through pressure from land use change (e.g. resulting from cultivation of new exotic and indigenous species around fragmented populations) and the activity of avian dispersers (Sultan *et al*., 2018) as *Scurrula pulverulenta* was observed in the current study on six exotic species. The addition to hosts of *Scurrula pulverulenta* also suggests that in more extensively explored areas, the number of host species encountered is obviously greater than in poorly collected areas as was also suggested by Downey (2004). Thus, more thorough surveys could potentially reveal additional hosts from other poorly explored areas (Sultan *et al*., 2018), moreover, in the absence of host inventories and information on regional host preferences, some of the new hosts may be overlooked (Downey, 2004). The occurrence of mistletoes on rare and exotic host suggests that the potential host range is large, but mistletoes are constrained by the fact the seeds are rarely disseminated to susceptible hosts (Sultan *et al*., 2018).

Over its whole range, *D. falcata* is known to have a very broad host range, being the second largest amongst the phanerogamic parasites (Ray & Dasgupta, 2011) with 401 host species from 227 genera in 77 families (Hawsworth *et al*., 1993) but we found a much smaller range of hosts in this study. Hence, rather than necessarily characterized by a wide host breadth, the large distributional range and geographic turnover in susceptible tree species may be more proximate drivers of the very large number of host species. Thus, the hosts used by a given parasite population may represent just a portion of the entire host range for a given species (Sultan, 2014). The absence on a usually frequently utilized host suggests that the host population in that region is genetically and physiologically different and resistant to infection or that the parasite has become locally adapted to an alternate host (Sultan, 2014).

Table 5. Host list for *Scurrula pulverulenta* (1–record supported by a herbarium specimen showing the host branch with mistletoe or record based on observation during current studies/record based on communication from a reliable source; 2–record on the herbarium sheet without host being collected; 3–literature record).

Host Family	Host genus	Host Species	Reliability level		
			1	2	3
Acanthaceae	*Justicia*	*J. adhatoda*	Pers. Obs.		
Anacardiaceae	*Pistacia*	*P. chinensis* subsp. *integerrima*	Pers. obs.		
Apocynaceae	*Carissa*	*C. spinarum*	Pers. obs.	RAW70977	Zakaullah *et al*., (1984)
	Nerium	*N. oleander*	Pers. obs.		
Cannabaceae	*Celtis*	*C.* sp.	Pers. obs.		
Euphorbiaceae	*Mallotus*	*M. philippensis*	Pers. obs.		Abdulla,1973
Fabaceae	*Senegalia*	*S. modesta*	Pers. obs. RAW100278		Zakaullah *et al*., (1984)
	Bauhinia	*B. variegata*	Pers. obs.		Zakaullah *et al*., (1984)
	Dalbergia	*D. sissoo*	Pers. obs.	RAW70977	Zakaullah *et al*., (1984), Abdulla, 1973
Juglandaceae	*Juglans*	*J. regia*	Pers. obs.		
Lamiaceae	*Colebrookea*	*C. oppositifolia*	RAW100279, Pers. obs.		
	Vitex	*V. negundo*	Pers. obs.		
Malvaceae	*Grewia*	*G. optiva*	Pers. obs.		
Moraceae	*Broussonetia**	*B. papyrifera**	Pers. obs.		Pundir,1995
	Morus	*M.* sp.	Pers. obs.		
		M. alba			Zakaullah *et al*., (1984)
		M. nigra	Pers. obs.		
	*Maclura**	*M. pomifera**	Pers. obs.		Zakaullah *et al*., (1984)
	Ficus	*F. auriculata*	Pers. obs.		Pundir,1995
		F. benghalensis	Pers. obs.		
		F. palmata	Pers. obs.		
		F. semicordata	Pers. obs.		
		F. sp.	.		Zakaullah *et al*., (1984)
Myrtaceae	*Callistemon**	*C.* sp.*			
	Psidium	*P. guajava*	Pers. obs.		
Oleaceae	*Olea*	*O. ferrugínea*	Pers. obs.	RAW70977	Zakaullah *et al*., (1984)
Punicaceae	*Punica*	*P. granatum*	Pers. obs.		Zakaullah *et al*., (1984)
Rhamnaceae	*Rhamnus*	*R. pentapomica*	RAW100280 Pers. obs.		
Rosaceae	*Prunus*	*P. armeniaca*	Pers. obs.		
	Pyrus	*P. pashia*	Pers. obs. RAW64500		
	Malus	*M. pumila*	Pers. obs.		
Rutaceae	*Citrus*	*C. jambhiri*	Pers. obs.		
Salicaceae	*Flacourtia*	*F. indica*			
	*Populus**	*P. nigra**	Pers. obs.		
	Salix	*S. acmophylla*	Pers. obs.	Pundir,1995	
Verbenaceae	*Duranta**	*D. erecta* *	Pers. obs.		
	*Lantana**	*L. camara**	RAW100281 Pers. obs.		
18 families	31 genera	37 species			
Indigenous	25 genera	31 species			
Exotic	6 genera	6 species			

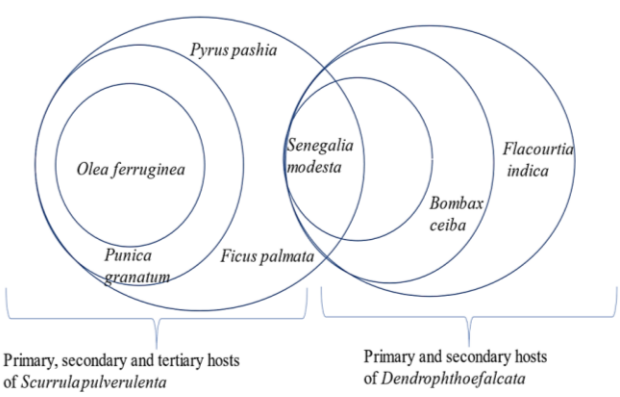

Fig. 15. Primary (innermost circle), secondary (first semi-circle) and tertiary hosts (outermost semi-circle) of *Scurrula pulverulenta* (left) and *Dendrophthoe falcata* (right).

Physical and chemical methods are employed to control mistletoe infestations. Physical method includes removal of infected branches of the host plant and chemical control involves spray of 2, 4-D and its derivatives. Timely removal of infected branches might prove to be the most effective control measure. Besides these two methods mixed plantations are also helpful for mistletoe control. Despite the damaging effects of mistletoes to forest and horticultural trees, mistletoe species are important food source for numerous wild life species like avian frugivores and for insects specializing on these mistletoes. Decline in mistletoe populations in many parts of the world highlights the importance of conserving these important keystone resources.

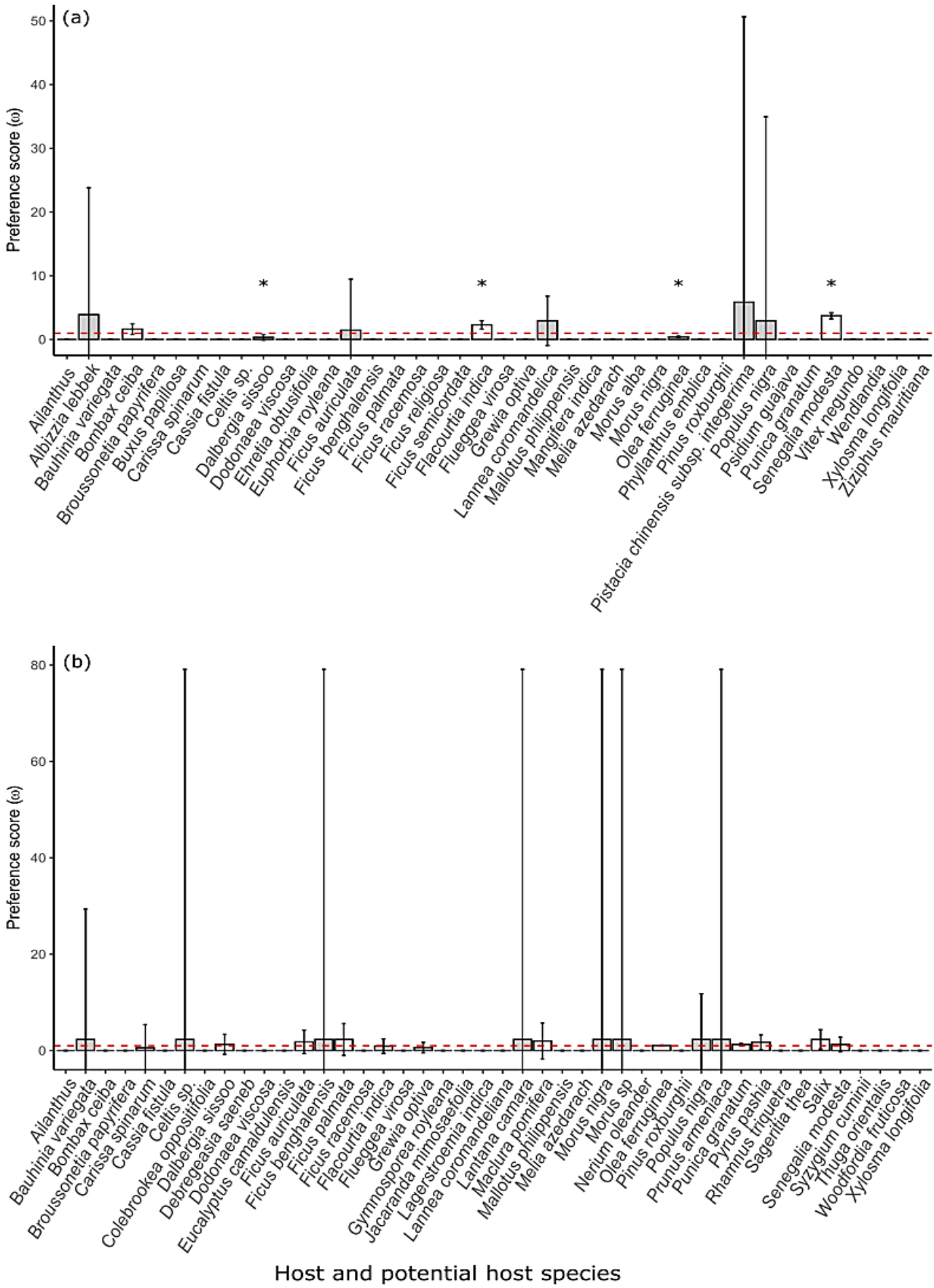

Fig. 16. Preference scores (ω) of *Dendrophthoe falcata* (a) and *Scurrula pulverulenta* (b). All nearest neighbor species surveyed appear on x-axis, those recorded as hosts have a preference score. Error bars represent 95% confidence intervals (CI). Dashed line shows ω = 1, species marked with * and a lower CI >1 are significantly preferred hosts, species marked with * and an upper CI <1 are significantly avoided hosts. ω of hosts with grey shaded bars should be treated with caution as <5 host-mistletoe interactions were recorded.

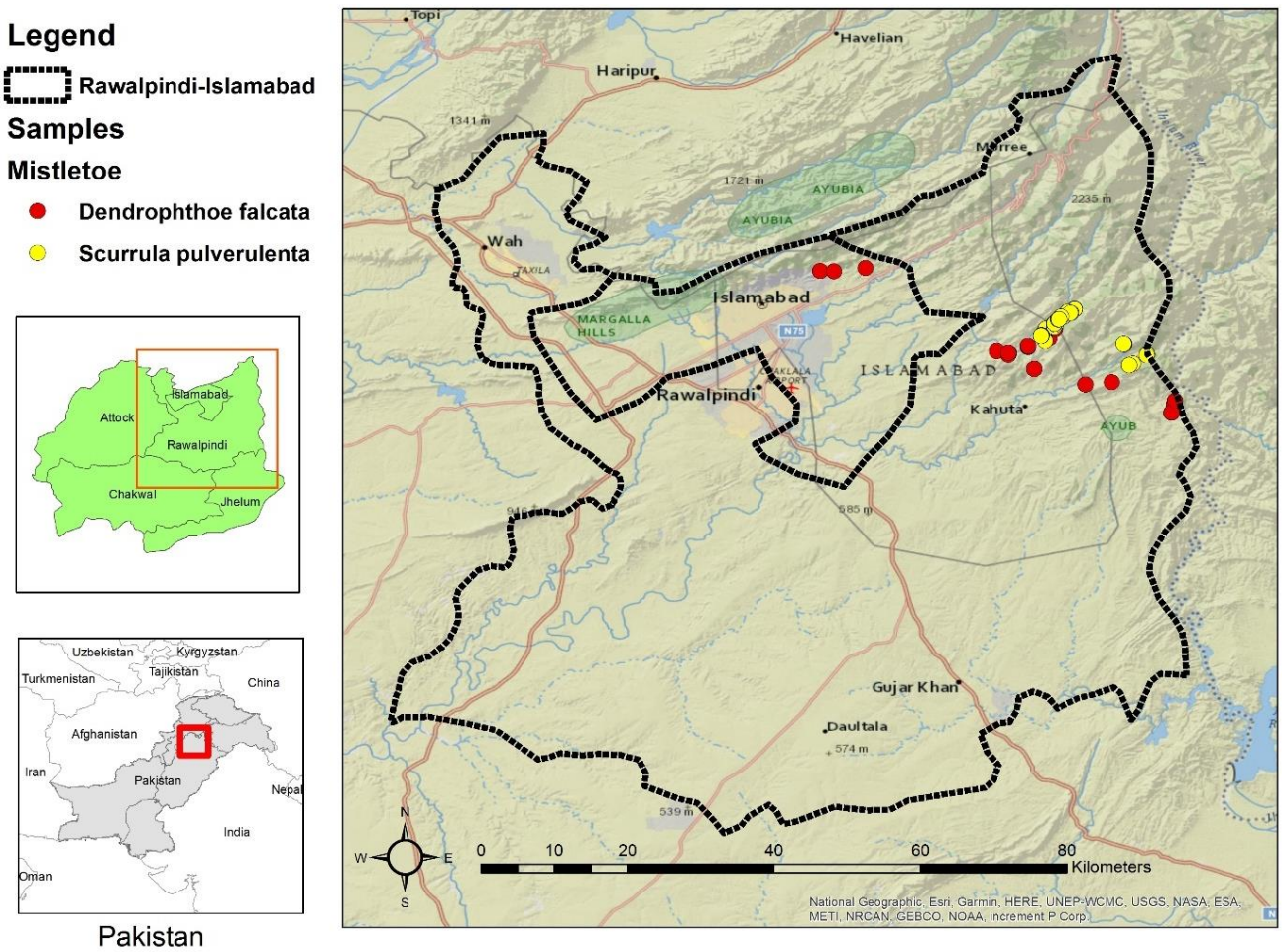

Fig. 17. Occurrence of *Dendrophthoe falcata* and *Scurrula pulverulenta*.

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